

EE C145B / BioE C165 Spring 2004:

Expectations for Final Exam

1. Know the frequency values on the axis on which the DFT is defined.
2. Be able to calculate the index of spectral peaks in a DFT.
3. Know how to draw the sinusoids each DFT coefficient represents.
4. Know that the 1D sinc function contains equal amounts of all frequencies up to a cutoff.
5. Know that the 2D jinc function contains equal amounts of all frequencies up to a cutoff.
6. Know what is meant by a singular matrix.
7. Understand the concepts of the range and the nullspace of a matrix.
8. Know that for every matrix there exists a decomposition $\mathbf{F} = \mathbf{U}\mathbf{S}\mathbf{V}^T$ where the columns of \mathbf{U} for which the corresponding singular values are non-zero span the range of \mathbf{F} . Know that the columns of \mathbf{V} for which the corresponding singular values are zero span the nullspace of \mathbf{F} . Know that \mathbf{S} has the singular values of \mathbf{F} along its diagonal in order of decreasing magnitude. Know the dimensions of these matrices.
9. Know that the columns of \mathbf{U} are orthonormal (unitary matrix).
10. Know that the columns of \mathbf{V} are orthonormal (unitary matrix).
11. Know how to modify \mathbf{S} to get the pseudoinverse of \mathbf{F} . Know that this pseudoinverse is the same as that derived by minimizing the sum of squared residuals for an overdetermined problem.
12. Be able to use the SVD to solve any system of linear equations.
13. Know how to interpret and when to manipulate the singular value spectrum.
14. Know two reasons why it is better to calculate the pseudoinverse via the SVD than by the direct formula.
15. Know how to use the SVD to approximate a matrix and compress images.
16. Understand how we can compare matrices using the sum of squared differences.
17. Be able to explain the difference between emission and transmission tomography in terms of: contrast mechanism and source of illumination.

18. Be able to calculate photon attenuation through different successive media.
19. Understand how we calculate a projection measurement in x-ray tomography.
20. Understand how we linearize this problem.
21. Understand the geometry of the Radon transform in 2D.
22. Be able to explain what a sinogram is, and be able to qualitatively draw a sinogram of a distribution.
23. Be able to show that each point in a distribution becomes a sinusoid in sinogram space.
24. Understand and know how to apply and explain the properties of the Radon transform.
25. Be able to interpret the projection slice theorem.
26. Know the steps needed to invert the 2D Radon transform using the projection theorem. Know two reasons why this is not a good idea in practice.
27. Understand what the backprojection operator does and be able to qualitatively draw a backprojection image given some projections.
28. Be able to derive the equation from which the backprojection-based reconstruction methods follow by means of the inverse FT, the projection slice theorem, and changes in integral limits.
29. Be able to explain where the ramp filter function comes from.
30. Be able to draw the ramp filter.
31. Be able to explain why this filter isn't realizable and explain why it performs poorly in the presence of noise.
32. Know the advantages and disadvantages of the modified ramp filters. Be able to qualitatively draw a modified ramp filter.
33. Understand the problem associated with implementing space-domain filtering of projections using the inverse FT of the ideal ramp filter (Hilbert transform of the derivative).
34. Know the steps involved in reconstructing images from projections using the four algorithms that involve backprojections and filtering (BCFP, BPFP, FFBP and SFBP).
35. Know how many angular and radial samples are needed to adequately sample a 2D distribution in Radon transform space.
36. Be able to derive these criteria.

37. Be able to form the discrete Radon transform projection matrix and know how to automatically determine the geometric weighting factors automatically.
38. Understand how to use the pseudoinverse to reconstruct tomographic images.
39. Know that the transpose of the projection matrix is the discrete back-projection operator.
40. Be able to explain the relationships between the pseudoinverse solution and the SFBP algorithm.
41. Understand the significance of the matrix $\mathbf{F}^T \mathbf{F}$ being block Toeplitz.
42. Be able to explain why we need iterative tomographic reconstruction algorithms.
43. Be able to apply the algebraic reconstruction technique (ART) to a simple example.
44. Know the basic properties of probability density functions and cumulative distribution functions.
45. Know how projection bin statistics can be modeled as Gaussian and Poisson random variables.
46. Understand the principle of maximum likelihood (ML) estimation.
47. Understand that the pseudoinverse is an ML estimate for a joint independent Gaussian distribution with unit parameter variances.
48. Know how to use a pseudoinverse engine to find WLS estimates.
49. Know the three assumptions made to qualify the arrival of photons at a detector as a Poisson process.
50. Know that in a Poisson process, the time intervals between events follow the exponential distribution.
51. Know the expressions for the mean and variance of the exponential distribution.
52. Know the expressions for the mean and variance of the Poisson distribution and Poisson process.
53. Know that the Poisson distribution tends towards a discrete Gaussian distribution as its mean increases.
54. Understand what makes the Poisson log likelihood function more difficult to maximize than the Gaussian likelihood function.
55. Know two reasons why we need to use optimization algorithms to minimize some functions.

56. Know the limitations of the exhaustive global search for optimal parameters.
57. Understand the basic concepts of gradient-based optimization methods.
58. Understand the concept of a local minimum.
59. Be able to calculate the steepest descent vector and execute a simple line search along it.
60. Understand the basic concepts of SPECT, contrast mechanisms, components of SPECT systems: gantry, collimator types, scintillator, PMTs.
61. Know sources of resolution loss in SPECT.
62. Know how a PMT works.
63. Understand basic physics of: photoelectric effect, Compton scatter, beta decay, positron emission, electron capture, internal conversion.
64. Know what is meant by: photopeak, Compton edge, backscatter peak, energy resolution and pulse height spectrum.
65. Be able to explain how we are able to reject most scattered photons.
66. Be able to identify the dominant scatter mechanism in living tissues when commonly used isotopes are employed.
67. Know why we must acquire projections over 360 degrees in ECT.
68. Know why we cannot use analytical methods for the solution of the Radon transform for SPECT image reconstruction.
69. Be able to flowchart/explain the process of reconstructing SPECT images given an x-ray CT attenuation map and a set of emission projections.
70. Know the pros and cons of tracers having long and short half lives.
71. Know the conditions under which positron emitting isotopes may be used for SPECT.
72. Know the sampling requirements for SPECT.
73. Understand basics of PET: physics and contrast mechanism.
74. Understand how collimation is achieved in PET and the pros and cons of electronic collimation.
75. Be able to compare PET and SPECT in terms of: collimation, spatial resolution, quantitation, timing resolution, tracers, complexity, cost, applications, sensitivity.
76. Know the purpose and pros and cons of interslice septa.
77. Know the different types of scintillator-PMT coupling and the benefits and drawbacks of each.

78. Understand Anger logic and its limitations.
79. Given properties of BGO and LSO, be able to explain why the one is superior/inferior to the other.
80. Be able to explain qualitatively why having time-of-flight information helps increase the SNR of reconstructed PET images.
81. Know the benefits and limitations of the Anger camera PET tomograph.
82. Be able to describe how we compensate for attenuation in PET.
83. Understand the concept of random coincidences and how these events can be rejected.
84. Know the three scans taken during a PET study and the purpose of each.
85. Understand the problem of scatter in PET.
86. Be able to explain why radial elongation leads to spatially variant degradation of resolution and how this can be overcome using depth-of-interaction information.
87. Be able to explain why photon non-collinearity occurs and why this is a fundamental resolution-limiting factor in PET.
88. Be able to explain the positron range effect and why this is a fundamental resolution-limiting factor in PET.
89. NMR: understand contrast mechanisms, classical model of nuclear spin, transverse and longitudinal relaxation, 90 degree pulse, 180 degree pulse, the meaning of T_1 , T_2 , T_2^* and proton spin density and factors affecting these quantities, quantum model of nuclear spin.
90. MRI: know the basic system components and function of each.
91. Understand the concepts of free induction decay and spin echo.
92. Be able to explain T_R and T_E and how these can be used to determine contrast and improve SNR in MRI.
93. Be able to explain why we sometimes repeat the 90 degree pulse and quantify the FID that results.
94. Understand factors affecting T_1 , T_2 and proton spin density in tissues.
95. Understand the effects of paramagnetism and paramagnetic tracers.
96. Understand frequency encoding of spatial position in MRI.
97. Know how to manipulate x and y gradient fields to perform projection MRI and reconstruct the distribution using the inverse RT.
98. Understand how transaxial slices are selected for imaging.

99. Understand phase encoding and that it simply corresponds to sampling the FT of the distribution along the v -axis.
100. Understand the purpose of each of the steps in the spin-warp sequence.
101. Be able to explain the process of acquiring all the RF signals necessary to perform 2D FT MRI, the process of assembling the signals into a matrix, and the application of the IDFT to the sampled signals.
102. Be able to explain mathematically how repeated spin-warp sequences sample 2D Fourier space.
103. Be able to compare MRI, x-ray CT, PET, SPECT, optical imaging and ultrasound with respect to: contrast agent, minimum detectable tracer concentration, functional contrast capabilities, maximum resolution, soft tissue contrast capabilities, bone imaging capabilities, ionizing radiation dose, slice scan time, audible noise, patient isolation from environment, effects of implants, system complexity, spectroscopic capabilities, flow measurement capabilities, timing resolution, tissue heating effects, equipment cost and clinical applications.
104. Be able to explain what an A-line represents.
105. Be able to explain what an M-mode image represents.
106. Be able to explain what an B-mode image represents.
107. Be able to explain CW Doppler and PW flow measurement.
108. Be able to explain diagrammatically how linear and phased array probes operate and how the latter steer a wavefront in a certain direction.
109. Be able to explain depth focussing in receive mode.
110. Be able to draw qualitatively-accurate sonograms for simple CW signals.
111. Be able to draw estimate the blood flow profile along the cross-section of a vessel from the sonogram.
112. Be able to describe the contributions of reflection at large surface boundaries, diffractive scatter and scatter in the Rayleigh region to the B-mode image.
113. Be able to describe the contribution of attenuation to the observed B-mode image.
114. Know the two types of projections that can be measured using ultrasound transmission tomography and the physical qualities affecting each.
115. Understand the resolution versus penetration frequency trade-off in ultrasound.